



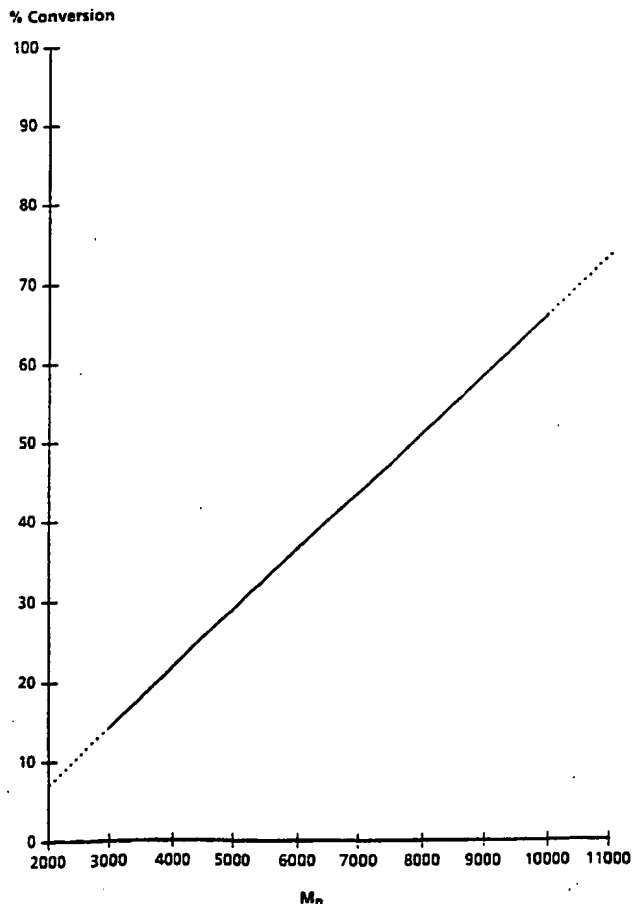
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/US93/09335 <b>(22) International Filing Date:</b> 1 October 1993 (01.10.93)  <b>(30) Priority data:</b> 07/976,604                      16 November 1992 (16.11.92) US  <b>(71) Applicant:</b> XEROX CORPORATION [US/US]; 800 Long Ridge Road, P.O. Box 1600, Stamford, CT 06904-1600 (US).  <b>(72) Inventors:</b> GEORGES, Michael, K. ; 384 Ironwood Road, Guelph, Ontario (CA). VEREGIN, Richard, P., N. ; 3515 Cherrington Crescent, Mississauga, Ontario (CA). KAZMAIER, Peter, M. ; 2421 Council Ring Road, Mississauga, Ontario (CA). HAMER, Gordon, K. ; #1-2280 South Millway, Mississauga, Ontario (CA).		<b>(74) Agents:</b> OLIFF, James, A. et al.; Oliff & Berridge, P.O. Box 19928, Alexandria, VA 22320 (US).  <b>(81) Designated States:</b> AU, BR, CA, KR, RU, UA, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.</i>

**(54) Title:** POLYMERIZATION PROCESSES AND TONER COMPOSITIONS THEREFROM

**(57) Abstract**

Disclosed is a free radical polymerization process for the preparation of a thermoplastic resin or resins comprising heating a mixture of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form a thermoplastic resin or resins with a high monomer to polymer conversion; cooling said mixture; optionally isolating the thermoplastic resin or resins; and optionally washing and drying thermoplastic resin or resins. Related free radical processes are also disclosed for the preparation of mixtures and block copolymer thermoplastic resins. Resins prepared by the disclosed processes possess a narrow polydispersity and a modality that is controlled by the selection of a free radical initiator and stable free radical agent addition step or steps. The figure is a plot of percent conversion versus molecular weight of a polystyrene homopolymer product obtained from a bulk or solventless stable free radical agent moderated polymerization of styrene at 130 degrees centigrade.



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**POLYMERIZATION PROCESSES AND TONER COMPOSITIONS THEREFROM**

**BACKGROUND OF THE INVENTION**

The present invention relates to processes for the preparation of polymers, and more specifically to a polymerization process and to the polymer formed thereby. In one embodiment, the present invention relates to a stable free radical moderated process for producing a thermoplastic polymer resin or resins, that have narrow polydispersities, that is, narrow molecular weight distributions as defined by the ratio  $M_w:M_n$ , where  $M_w$  is weight average molecular weight and  $M_n$  is number average molecular weight, and easily controllable modality, from at least one monomer compound comprising heating for an effective period of time a mixture of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound under conditions such that all polymer chain formations are initiated at about the same time; cooling the mixture to effectively terminate the polymerization; isolating the thermoplastic resin product; and optionally washing and drying the polymer resins. The polymer resins produced by the process of the present invention in embodiments are essentially monomodal and in embodiments by repeating the heating step, that is, the combined initiation and polymerization step, provides a means for obtaining mixtures of monomodal polymer resins, that are compositionally the same resin type having characteristics of both narrow polydispersity and known or selectable modality. In another embodiment the process of the instant invention provides a means for conducting bulk or neat free radical polymerization processes on multikilogram or larger scales. The aforementioned embodiments may be accomplished in a one or single pot reactor environment. In another embodiment polymeric chain growth proceeds by a pseudoliving mechanism and can provide resins of variable molecular weights from very low to very high, for example, less than about 10,000 up to about 200,000 while maintaining narrow molecular weight distributions or polydispersities. In another embodiment block copolymers can be synthesized by the aforementioned stable free radical moderated free radical polymerization processes wherein each block formed is well defined in length by the reacted monomer and wherein each block formed possesses a narrow molecular weight distribution.

Of the known polymerization processes a preferred way to prepare polymers or copolymers having a narrow molecular weight distribution or polydispersity is by anionic processes. The use and

availability of resins having narrow polydispersities in industrial applications is limited because anionic polymerization processes must be performed in the absence of atmospheric oxygen and moisture, require difficult to handle and hazardous initiator reagents and consequently such polymerization processes are generally limited to small batch reactors. In addition, the monomers and solvents that are used must be of high purity and anhydrous rendering the anionic process more expensive than alternatives which do not have these requirements. Thus, anionic polymerization processes are difficult and costly. It is desirable to have a free radical polymerization process that would provide narrow molecular weight distribution resins that overcome the shortcomings and disadvantages of the aforementioned anionic polymerization processes.

Free radical polymerization processes are chemically less sensitive to impurities in the monomers or solvents typically used and are completely insensitive to water. There has been a long felt need for an economical free radical polymerization process which is suitable for preparing narrow polydispersity resins by suspension, solution, bulk or neat, emulsion and related processes.

Copolymers prepared by free radical polymerization processes inherently have broad molecular weight distributions or polydispersities, generally greater than about five. One reason is that free radical initiators have half lives that are relatively long, from several minutes to many hours, and polymeric chains are not all initiated at the same time and which initiators provide growing chains of various lengths at any time during the polymerization process. Another reason is that the propagating chains in a free radical process can react with each other in processes known as coupling and disproportionation, both of which are chain terminating reactions. In doing so, chains of varying lengths are terminated at different times during the reaction process which results in resins comprised of polymeric chains which vary widely in length from very small to very large. If a free radical polymerization process is to be enabled for producing narrow molecular weight distributions, then all polymer chains must be initiated at about the same time and premature termination by coupling or disproportionation processes must be avoided.

Otsu et.al., in Makromol Chem., Rapid Commun., 3, 127 (1982), introduced the use of iniferters as a means of producing block copolymers by a free radical polymerization process. A mechanism proposed for the reaction suggested that a pseudoliving propagating free radical chain exists and that it continues to grow with time. There are two major

drawbacks associated with using iniferters. Iniferters tend to react very slowly and the percent conversion or degree of polymerization of monomer to polymer is low, for example, about 40 percent even after 20 hours of reaction time. Another drawback is that the free radical trap that caps the end of the growing chain has the ability to initiate new chains at any time during the course of the reaction, see for example, S.R.Turner, R.W.Blevins, in Polymer Reprints, 29(2), Sept.1988. This initiation leads to new chains being initiated at various times during the polymerization and consequently leads to broadening of the polydispersity. Although the approach in the aforementioned reference of Otsu was novel in using pseudoliving free radical propagating chains, it was not applicable to the synthesis of narrow molecular weight distribution resins particularly for polymers with high molecular weights.

The use of stable free radicals are well known as inhibitors of free radical polymerizations, see for example, G. Moad et.al., Polymer Bulletin 6, 589 (1982). Studies by, for example, G. Moad et.al. J.Macromol. Sci.-Chem., A17(1), 51(1982) have reported on the use of stable free radicals as inhibitors of free radical polymerizations performed at low temperatures, for example, below 90°C and at low monomer to polymer conversions. Little is known concerning the reaction of stable free radical agents at higher temperatures and at high monomer to polymer conversions.

In a hypothetical free radical polymerization of styrene, in which chains are continually initiated over the course of the polymerization, and where chain termination by coupling processes is also occurring, calculations as described in, for example, G. G. Odian, Principles of Polymerization, pages 280 - 281, 2nd Ed., John Wiley & Sons, 1981 have shown that the narrowest polydispersity that one can theoretically possibly obtain is 1.5. In practice, polydispersities much greater than 1.5 are actually obtained. Polydispersities of between 2.0 and 2.4 are typical for free radical homopolymerizations of styrene. In the case of copolymer systems, polydispersities of greater than 4 are generally obtained.

The stable free radical polymerization system of the instant invention may readily afford polydispersities of between 1.15 and 1.25 for polystyrene and as low as 1.5 for various copolymer systems. Stable free radical polymerization systems of the instant invention afford polydispersities that are comparable to those obtained in anionic polymerizations.

In a patentability search report the following patents were recited:

U.S. Patent 4,581,429 to Solomon et al., issued April 8, 1986, discloses a free radical polymerization process which controls the growth of polymer chains to produce short chain or oligomeric homopolymers and copolymers including block and graft copolymers. The process employs an initiator having the formula (in part)  $=N-O-X$ , where X is a free radical species capable of polymerizing unsaturated monomers. The molecular weights of the polymer products obtained are generally from about 2,500 to 7,000 having polydispersities generally of about 1.4 to 1.8, at low monomer to polymer conversion. The reactions typically have low conversion rates and use relatively low reaction temperatures of less than about 100 degrees C, and use multiple stages.

U.S. Patent 5,059,657 to Druliner et al., issued October 22, 1991, discloses a polymerization process for acrylic and maleimide monomers by contacting the monomers with a diazotate, cyanate or hyponitrite, and N-chlorosuccinimide, N-bromosuccinimide or a diazonium salt. The polymer produced can initiate further polymerization, including use in block copolymer formation.

The following references are also of interest: U.S. Patents 3,682,875; 3,879,360; 3,954,722; 4,201,848; 4,777,230; 5,173,551; and 5,216,096.

In free radical polymerization reaction processes of the prior art, various significant problems exist, for example difficulties in predicting or controlling the polydispersity and modality of the polymers produced. These free radical polymerization processes invariably produce polymers with high weight average molecular weights ( $M_w$ ) and low number average molecular weights ( $M_n$ ) resulting in broad polydispersities. Further, bulk or neat free radical polymerization processes of the prior art are prone to generating excessive quantities of heat since the polymerization reaction is exothermic and as the viscosity of the reaction medium increases dissipation of heat becomes more difficult. This is referred to as the Trommsdorff effect as discussed and illustrated in Principles of Polymerization, G. Odian, 2nd Ed., Wiley-Interscience, N.Y., 1981, page 272, the disclosure of which is entirely incorporated herein by reference. Moreover, the exothermic nature of free radical polymerization processes is often a limitation that severely restricts the concentration of reactants or the reactor size upon scale up.

It is known to form resins by bead suspension polymerization reference for example U.S. Patents 4,601,968 and 4,609,607, the disclosures of which are totally incorporated herein by reference.

5 Illustrated in copending application USSN 07/812,082, filed December 23, 1991 (D/90515), the disclosure of which is incorporated by reference herein in its entirety, is that free radical suspension polymerization reactions may also lead to undesirable deposits of polymer on the agitator, baffles, heating coils and reactor walls. In some situations, the suspension coalesces during the reaction producing large deposits of  
10 undesirable polymeric gel material which is difficult, expensive and hazardous to remove from the reactor.

Further, gel body formation in conventional free radical polymerization processes may result in a broad molecular weight distributions and/or difficulties encountered during filtering, drying and  
15 manipulating the product resin.

These and other disadvantages are avoided, or minimized with the processes of the present invention.

Thus, there remains a need for processes for the preparation of narrow polydispersity polymeric resins by economical and scalable free  
20 radical polymerization techniques and which polymers retain many or all of their desirable physical properties, for example, hardness, low gel content, processability, clarity, high gloss durability, and the like, while avoiding the problems of gel formation, exotherms, volume limited and multi-stage reaction systems, purification, performance properties of the  
25 polymer resin products, and the like associated with prior art free radical polymerization methodologies.

The polymerization processes and thermoplastic resin products of the instant invention are useful in many applications, for example, as a variety of specialty applications including toner resins used for  
30 electrophotographic imaging processes or where monomodal or mixtures of monomodal narrow molecular weight resins or block copolymers with narrow molecular weight distribution within each block component are suitable such as in thermoplastic films and coating technologies.

#### **SUMMARY OF THE INVENTION**

35 An object of the present invention is to provide processes and polymers that overcome many of the problems and disadvantages of the aforementioned prior art.

Another object of the instant invention is to provide a free radical polymerization reaction system which affords narrow

polydispersity homopolymeric or copolymeric thermoplastic resin products.

5 In another object of the instant invention is to provide a free radical polymerization reaction system which may be conducted in the presence or absence of conventional reaction media.

In yet another object of the instant invention, coupling or disproportionation termination reactions are prevented by reversibly terminating the propagating free radical chains with a stable free radical agent which serves to moderate the free radical polymerization process.

10 In another object of the instant invention is provided the acceleration of the dissociation of the free radical peroxide initiator by the addition of promoter compounds which include, for example, tertiary amines, which ensure that all polymeric chains are initiated nearly simultaneously or about the same time.

15 In another object of the instant invention is the addition of small amounts of organic acids, for example, sulfonic or carboxylic acids, to the reaction medium to increase the rate of reaction without broadening the polydispersity of the polymeric resins.

20 Still another object of the instant invention is to prepare thermoplastic resins by single pot processes employing a monomer or monomers, a suitable azo or peroxide free radical initiator, and a stable free radical agent.

25 Another object of the instant invention is to prepare resins using polymerization processes wherein the molecular weight of the growing copolymer chains increase over the entire time period of the polymerization reaction and wherein the percent conversion or degree of polymerization of monomer to polymer with respect to time or number average molecular weight is approximately linear, that is, polymerization processes which occur without the aforementioned Trommsdorff effect.

30 In embodiments, the present invention overcomes the problems and disadvantages of the prior art by forming narrow polydispersity polymeric resins by means, for example, a free radical polymerization process comprising heating a mixture of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to  
35 form thermoplastic resin or resins with a high monomer to polymer conversion; cooling the mixture; optionally isolating said thermoplastic resin or resins; and optionally washing and drying the thermoplastic resin or resins and wherein the thermoplastic resin or resins possess a narrow polydispersity.



Another embodiment of the present invention is a free radical polymerization process for the preparation of thermoplastic resins comprising heating a first mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form a first intermediate product resin; optionally cooling the first mixture; adding to the first intermediate product resin a second mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound, wherein the polymerizable monomer compound of the second mixture is the same as the polymerizable monomer compound of the first mixture, and the free radical initiator and the stable free radical agent of the second mixture are the same or different from the free radical initiator and the stable free radical agent of the first mixture, to form a combined mixture; heating the combined mixture to form a third mixture comprised of a mixture of thermoplastic resins comprised of a first product resin formed from the first intermediate product resin and added the second monomer and a second product resin formed from the second monomer; cooling the third mixture; optionally isolating the mixture of thermoplastic product resins from the third mixture; and optionally washing and drying the mixture of thermoplastic resins and wherein the first product resin and the second product resin each possess a narrow polydispersity and the mixture of thermoplastic resins possesses a modality equal to 2. Higher modalities, for example, of from 3 to about 20 may be conveniently achieved if desired by the subsequent addition of fresh mixtures of monomer, free radical initiator and stable free radical agent prior to a final cooling and isolation step.

In another embodiment of the instant invention is a free radical polymerization process for the preparation of a block copolymer thermoplastic resin or resins comprising heating a first mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form a first intermediate product resin; optionally cooling the first mixture; optionally isolating the first intermediate product resin; adding to the first intermediate product resin a second mixture comprised of at least one polymerizable monomer compound, wherein the polymerizable monomer compound of the second mixture is different from the polymerizable monomer compound of the first mixture, to form a combined mixture; heating the combined mixture to form a third mixture comprised of a block copolymer thermoplastic resin comprised of a first product resin formed from the first intermediate

product resin and added the second monomer; cooling the third mixture; optionally isolating the block copolymer thermoplastic resin from the third mixture; and optionally washing and drying the block copolymer thermoplastic resin and wherein the block copolymer possesses a narrow polydispersity and a modality equal to 1. The isolation of the intermediate product resin is preferred when highest purity and block integrity or homogeneity is desired, that is, residual unreacted monomer or monomers of the first mixture may subsequently react with and be integrated into the growing polymer chain formed from the second mixture of polymerizable monomer compounds. Thus, in preparing block copolymers by processes of the instant invention isolation by, for example, precipitation of intermediate products of polymerization reactions is preferred when high purity is desired or when the degree of polymerization is less than about 70 to 90 percent for a block or multiblock polymerization reaction.

In yet another embodiment of the present invention is a free radical polymerization process for the preparation of a thermoplastic resin comprising heating for an effective period a water suspension mixture of a peroxide free radical initiator, a nitroxide stable free radical agent, and at least one polymerizable monomer compound to form the thermoplastic resin with a high monomer to polymer conversion; cooling the mixture; isolating the thermoplastic resin; and optionally washing and drying the thermoplastic resin and wherein the thermoplastic resin possesses a narrow polydispersity of about 1.1 to about 1.5 and a modality of 1.

In embodiments of the aforementioned processes, polymer or copolymer resin compositions are obtained wherein the resin or resins has a weight average molecular weight ( $M_w$ ) of from about 10,000 to 200,000 and a number average molecular weight ( $M_n$ ) of from about 9,000 to about 100,000 and a polydispersity of about 1.1 to 2.0.

Although not being desired to be limited by theory, it is believed that when polymerization reaction processes of the instant invention are performed at a temperature at about or above 100 degrees C, the exact temperature depending on the initiator used, all the polymer chains are expected to be initiated at about the same time which is a primary reason for enabling forming polymer chain products having narrow polydispersities.

The aforementioned undesirable chain coupling or disproportionation termination reactions, so prevalent under the conditions of the prior art free radical polymerization systems, is suppressed under the conditions of the instant invention because the

effective concentration and availability of living free chains is extremely small. In addition, stable free radical agents of the instant invention do not initiate polymerization so that new chains are not initiated after an initial period during which all polymer chains are initiated at about the same time.

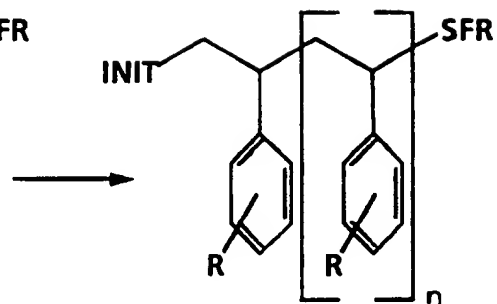
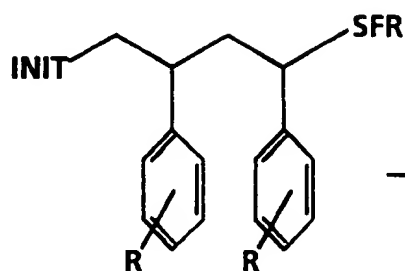
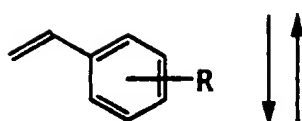
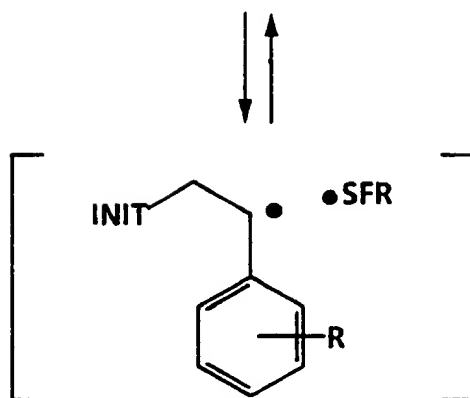
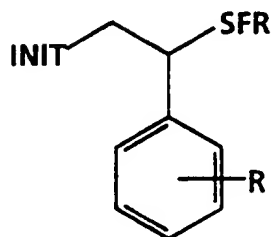
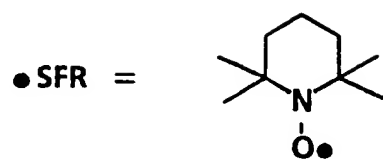
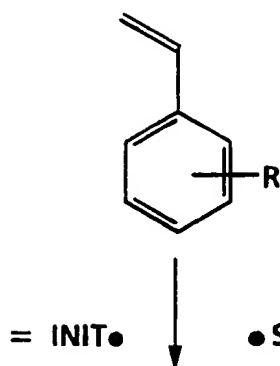
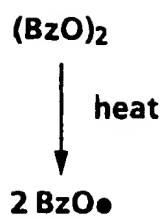
5 Propagating chains of the instant invention are referred to as pseudoliving because the stable free radical agent adds to a propagating chain and the chain is temporarily, but reversibly, terminated. As shown in the accompanying scheme, the propagating polymer chain fluctuates or is  
10 in an equilibrium condition between being temporarily terminated or suspended and being alive or living. As thermal energy is supplied from the reaction system to the bond joining the growing polymeric chain and the stable free radical (●SFR) agent, that is, the adduct in the accompanying scheme where, for example, the stable free radical agent  
15 (●SFR) is covalently bound to the propagating chain, for example, a substituted styrene, homolytically cleaves thereby temporarily generating a living chain end radical species shown in square brackets[] permitting another monomer unit to insert or add to the chain and is again instantaneously, albeit short lived as determined by diffusion control,  
20 terminated or protected by the stable free radical agent as a thermally labile adduct above about 80° to 100° C or latent free radical chain. The free radical initiator, for example, benzoyl peroxide, is represented in the scheme as ●INIT. The term "protected" as used herein is meant to suggest that the chain radical species is available for selective rather than  
25 indiscriminant further reaction with monomer. An unmoderated free radical polymerization chain, that is, a free radical polymerization process without a stable free radical agent present, in contrast has a reactive or "open" chain end throughout the reaction.

Processes of the present invention further comprises in an  
30 embodiment a means for sequentially repeating the monomer addition or polymerization step and with additional stable free radical and free radical initiator of the process being added, N times, to provide a well defined mixture of thermoplastic resins wherein each resin in the mixture is comprised of polymers having discrete and narrow polydispersities and  
35 wherein the mixture has a modality equal to  $N + 1$  wherein N is the number of times the addition step of initiator, stable free radical agent and monomer is repeated.

The present invention provides several specific advantages in embodiments as follows.

With the process of the present invention, polymer product polydispersities can be varied from between approximately 1.1 to approximately 2.0 depending on the monomer/comonomer system by varying the ratio of stable free radical agent to free radical initiator molar concentration. When the polymerization process conditions of the present invention are attempted without using the a SFR additive, broad molecular weight resins are obtained.

The stable free radical agent moderated polymerization reactions may be performed in a variety of media for example, suspension, emulsion, bulk, that is neat or without solvent, or in aqueous or non-aqueous solution, using preferably higher boiling solvents such as, toluene and xylene.



During the reaction of monomer or mixed monomers to form polymers, the reaction time may be varied over about 1 to 60 hours, preferably between about 2 to 10 hours and optimally about 4 to 7 hours. The optimal reaction time may vary depending upon the temperature, the volume and scale of the reaction, and the quantity and type of polymerization initiator and stable free radical agent selected.

The polymerization reaction temperature is kept relatively constant throughout the heating step by providing an adjustable external heat source and the temperature is from about 60°C to about 160°C, and preferably between 100°C and 150°C and optimally in embodiments about 120°C to 140°C. Reactions performed above 160°C tend to result in a broadening of the polydispersity. A reaction volume may be selected for any size that enables simple adding, mixing, reacting and isolating the product resins on an economic or convenient scale.

The free radical initiator can be any free radical polymerization initiator capable of initiating a free radical polymerization process and includes peroxide initiators such as benzoyl peroxide and azo initiators such as azobisisobutyronitrile, and the like. The initiator concentration employed is about 0.2 to 2.5 weight percent, of the total weight of monomer to be polymerized and is determined by the desired molecular weight of the resin. As the initiator concentration is decreased relative to the weight of molar equivalents of monomer used, the molecular weight of the thermoplastic resin product increases.

The stable free radical agent can be any stable free radical and includes nitroxide free radicals, for example, PROXYL (2,2,5,5-tetramethyl-1-pyrrolidinyloxy) and derivatives thereof, and TEMPO (2,2,6,6-tetramethyl-1-piperidinyloxy) and derivatives thereof, and the like. These stable free radical agent materials are well known in the literature, for example G. Moad et.al., Tetrahedron Letters, 22, 1165 (1981) as free radical polymerization inhibitors. However, under the polymerization conditions of the instant invention stable free radical agents function as moderators to harness the normally highly reactive and indiscriminate intermediate free radical species.

The molar ratio of the stable free radical (SFR) agent to free radical initiator (INIT) is from about 0.4 to 2.5, and preferably in the range from about 0.9 to 1.6. Although not wanting to be limited by theory, in an embodiment, the molar ratio [SFR:INIT.] of stable free radical agent, for example, TEMPO, to free radical initiator, for example, benzoyl peroxide, of about 1.3 is believed to be important for success of the process. If the

[SFR:INIT.] is too high then the reaction rate is noticeably inhibited. If the [SFR:INIT.] is too low then the reaction product has undesired increased polydispersity. It should be noted that when styrene is polymerized to polystyrene without the stable free radical agent of the instant process the product polymers isolated have polydispersities of 2.0 and above.

In embodiments, the molar ratio of monomer content to stable free radical agent to free radical initiator is from about 100:0.2:1 to about 10,000:2.5:1 and preferably in the range of about 300:1.3:1 to about 7,000:1.3:1.

Processes of the instant invention, in embodiments, provide for high monomer to polymer conversion rates, or degrees of polymerization, for example of 90 percent by weight or greater.

Processes of the instant invention, in embodiments provide for relatively high weight average molecular weights, from weight average molecular weights ranging in size of from about 10,000 to about 200,000.

The monomers that can be used are any monomer capable of undergoing a free radical polymerization and include but are not limited to styrene, substituted styrenes and derivatives thereof, for example methylstyrene, acrylates, methacrylates, butadiene and any conjugated diene monomer sufficiently reactive under the specified stable free radical moderated polymerization reaction conditions to afford a stable free radical reaction adduct and high molecular weight polymer product for example, isoprene and myrcene.

The polymerization reaction rate of the monomers may, in embodiments, be accelerated and the reaction time reduced to about 4 to 7 hours from greater than 16 hours by the addition of a catalytic amount of a protic acid, that will not also initiate cationic polymerization, selected from the group consisting of organic sulfonic and carboxylic acids where camphorsulfonic acid is a preferred acid and where the molar ratio of stable free radical to acid is from about 1:1 to 11:1, with a preferred ratio of between about 1.5:1 and 5:1. Excessive addition of organic acid beyond the aforementioned amounts causes the resin polydispersity to broaden.

The stable free radical moderated polymerization process of the instant invention may be repeated a number of times within the same reaction vessel by the delayed and stepwise addition of more monomer or monomers with varying amounts of initiator and stable free radical agent to form a mixture of monomodal resins where each component has a distinct molecular weight and has a narrow molecular weight distribution and wherein the mixture has a modality of  $N + 1$ , where  $N$  represents the

number of additional times that monomer, initiator and stable free radical agent are added.

By cooling the polymerization reaction to below 60 to 80°C, the stable free radical moderated reaction is effectively quenched or terminated. Each new or subsequent addition of monomer, stable free radical and initiator accompanied by heating provides a new polymeric species having a narrow molecular weight distribution and each new polymer species continues to grow independent of the other polymer species already established.

Alternatively, block copolymer resins may also be prepared whereby after each desired block has been formed a new monomer or monomers is added without the addition of more initiator or stable free radical agent to form a new block wherein each block component is well defined in length and has a narrow molecular weight distribution and having properties depending on the repeated sequence and the monomers chosen for incorporation.

Additional optional known additives may be used in the polymerization reactions which do not interfere with the objects of the invention and which may provide additional performance enhancements to the resulting product, for example, colorants, lubricants, release or transfer agents, surfactants, stabilizers, antifoams, and the like.

Polymer resins possessing discrete mixture of monomodal, that is a well defined multimodal molecular weight distribution may in embodiments thereof provide several advantages, particularly for electrophotographic toner compositions such as: melt rheology properties including improved flow and elasticity; and improved performance properties such as triboelectrification, admix rates and shelf life stabilities.

The processes of the present invention can be selected to form a wide variety of polymers. For example, it can be used to polymerize a styrene monomer to form polystyrene or butadiene to form polybutadiene. The process of the present invention can be selected to polymerize a mixture of two or more different polymerizable monomers to form copolymers therefrom, for example, polymerization of styrene and butadiene to form poly(styrene-butadiene), styrene and isoprene to form poly(styrene-isoprene), styrene and acrylate to form poly(styrene-acrylate), styrene and methyl methacrylate to form poly(styrene-methyl methacrylate), and the like, and combinations thereof, including copolymers and terpolymers.



A suitable reaction medium employed for conducting processes of the instant invention may be selected from the group consisting of bulk or neat, suspension, emulsion, and solution systems.

#### **BRIEF DESCRIPTION OF THE DRAWING**

5           Figure 1 is a plot of percent conversion versus molecular weight of a polystyrene homopolymer product obtained from a bulk or solventless stable free radical agent moderated polymerization of styrene at 130 degrees centigrade.

10           In an embodiment, reference Figure 1, a monomer is polymerized in bulk or in the absence of a solvent or diluent, that is neat, using a mixture of styrene monomer, a free radical initiator, and a stable free radical agent at constant temperature. A plot of weight percent monomer conversion versus number average molecular weight indicates that a nearly linear relationship holds for this bulk polymerization and  
15           other aforementioned reaction media using stable free radical agent moderated processes of the instant invention. For example, at 20 percent conversion the number average molecular weight of the polystyrene polymer product is about 4,000 and at 65 percent conversion the number average molecular weight is about 10,000. The solid line slope of the plot  
20           was obtained by known best fit linear regression methods and supports the aforementioned belief that polymerization processes of the instant invention occur without complications arising from the known Trommsdorff effect, that is, known exothermic heating or autoacceleration of the monomer conversion reaction rate and  
25           randomization of molecular weights observed in unmoderated free radical polymerization reactions.

          In embodiments, there can be incorporated into the monomer a waxy component, such as alkylenes, like polyethylene, polypropylene waxes, and mixtures thereof having a low molecular weight of from  
30           between about 1,000 to about 20,000. The use of such a component may be desirable for certain toner applications. Suitable low molecular weight waxes are disclosed in U.S. Patent 4,659,641, the disclosure of which is totally incorporated herein by reference.

          Toner compositions can be prepared by a number of known  
35           methods, such as admixing and heating resin particles obtained with the processes of the instant invention such as styrene butadiene copolymers, pigment particles such as magnetite, carbon black, or mixtures thereof, and cyan, yellow, magenta, green, brown, red, or mixtures thereof, and preferably from about 0.5 percent to about 5 percent of charge enhancing

additives in a toner extrusion device, such as the ZSK53 available from Werner Pfleiderer, and removing the formed toner composition from the device. Subsequent to cooling, the toner composition is subjected to grinding utilizing, for example, a Sturtevant micronizer for the purpose of achieving toner particles with a volume median diameter of less than about 25 microns, and preferably of from about 6 to about 12 microns, which diameters are determined by a Coulter Counter. Subsequently, the toner compositions can be classified utilizing, for example, a Donaldson Model B classifier for the purpose of removing toner fines, that is toner particles less than about 4 microns volume median diameter.

Illustrative examples of suitable toner resins selected for the toner and developer compositions of the present invention include polyamides, styrene acrylates, styrene methacrylates, styrene butadienes, vinyl resins, including homopolymers and copolymers of two or more vinyl monomers; vinyl monomers include styrene, p-chlorostyrene, butadiene, isoprene, and myrcene; vinyl esters like esters of monocarboxylic acids including methyl acrylate, ethyl acrylate, n-butyl acrylate, isobutyl acrylate, dodecyl acrylate, n-octyl acrylate, phenyl acrylate, methyl methacrylate, ethyl methacrylate, and butyl methacrylate; acrylonitrile, methacrylonitrile, acrylamide; and the like. Preferred toner resins include styrene butadiene copolymers, mixtures thereof, and the like. Other preferred toner resins include styrene/methacrylate copolymers, PLIOLITES®; suspension polymerized styrene butadienes, reference U.S. Patent 4,558,108, the disclosure of which is totally incorporated herein by reference.

In toner compositions, the resin particles are present in a sufficient but effective amount, for example from about 70 to about 90 weight percent. Thus, when 1 percent by weight of the charge enhancing additive is present, and 10 percent by weight of pigment or colorant, such as carbon black, is contained therein, about 89 percent by weight of resin is selected. Also, the charge enhancing additive may be coated on the pigment particle. When used as a coating, the charge enhancing additive is present in an amount of from about 0.1 weight percent to about 5 weight percent, and preferably from about 0.3 weight percent to about 1 weight percent.

Numerous well known suitable pigments or dyes can be selected as the colorant for the toner particles including, for example, carbon black like REGAL 330®, nigrosine dye, aniline blue, magnetite, or mixtures thereof. The pigment, which is preferably carbon black, should

be present in a sufficient amount to render the toner composition highly colored. Generally, the pigment particles are present in amounts of from about 1 percent by weight to about 20 percent by weight, and preferably from about 2 to about 10 weight percent based on the total weight of the toner composition; however, lesser or greater amounts of pigment particles can be selected.

When the pigment particles are comprised of magnetites, thereby enabling single component toners in some instances, which magnetites are a mixture of iron oxides ( $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ ) including those commercially available as Mapico Black, they are present in the toner composition in an amount of from about 10 percent by weight to about 70 percent by weight, and preferably in an amount of from about 10 percent by weight to about 50 percent by weight. Mixtures of carbon black and magnetite with from about 1 to about 15 weight percent of carbon black, and preferably from about 2 to about 6 weight percent of carbon black, and magnetite, such as MAPICO BLACK®, in an amount of, for example, from about 5 to about 60, and preferably from about 10 to about 50 weight percent can be selected.

There can also be blended with the toner compositions of the present invention external additive particles including flow aid additives, which additives are usually present on the surface thereof. Examples of these additives include colloidal silicas, such as AEROSIL®, metal salts and metal salts of fatty acids inclusive of zinc stearate, aluminum oxides, cerium oxides, and mixtures thereof, which additives are generally present in an amount of from about 0.1 percent by weight to about 5 percent by weight, and preferably in an amount of from about 0.1 percent by weight to about 1 percent by weight. Several of the aforementioned additives are illustrated in U.S. Patents 3,590,000 and 3,800,588, the disclosures of which are totally incorporated herein by reference.

With further respect to the present invention, colloidal silicas, such as AEROSIL®, can be surface treated with the charge additives in an amount of from about 1 to about 30 weight percent and preferably 10 weight percent followed by the addition thereof to the toner in an amount of from 0.1 to 10 and preferably 0.1 to 1 weight percent.

Also, there can be included in the toner compositions low molecular weight waxes, such as polypropylenes and polyethylenes commercially available from Allied Chemical and Petrolite Corporation, EPOLENE N-15® commercially available from Eastman Chemical Products, Inc., VISCOL 550-P®, a low weight average molecular weight polypropylene

available from Sanyo Kasei K.K., and similar materials. The commercially available polyethylenes selected have a molecular weight of from about 1,000 to about 1,500, while the commercially available polypropylenes utilized for the toner compositions are believed to have a molecular weight of from about 4,000 to about 5,000. Many of the polyethylene and polypropylene compositions useful in the present invention are illustrated in British Patent No. 1,442,835, the disclosure of which is totally incorporated herein by reference.

The low molecular weight wax materials are present in the toner composition or the polymer resin beads of the present invention in various amounts, however, generally these waxes are present in the toner composition in an amount of from about 1 percent by weight to about 15 percent by weight, and preferably in an amount of from about 2 percent by weight to about 10 percent by weight and may in embodiments function as fuser roll release agents.

Encompassed within the scope of the present invention are colored toner and developer compositions comprised of toner resin particles, carrier particles, the charge enhancing additives illustrated herein, and as pigments or colorants red, blue, green, brown, magenta, cyan and/or yellow particles, as well as mixtures thereof. More specifically, with regard to the generation of color images utilizing a developer composition with charge enhancing additives, illustrative examples of magenta materials that may be selected as pigments include, for example, 2,9-dimethyl-substituted quinacridone and anthraquinone dye identified in the Color Index as CI 60710, CI Dispersed Red 15, diazo dye identified in the Color Index as CI 26050, CI Solvent Red 19, and the like. Illustrative examples of cyan materials that may be used as pigments include copper tetra-4-(octadecyl sulfonamido) phthalocyanine, X-copper phthalocyanine pigment listed in the Color Index as CI 74160, CI Pigment Blue, and Anthrathrene Blue, identified in the Color Index as CI 69810, Special Blue X-2137, and the like; while illustrative examples of yellow pigments that may be selected are diarylide yellow 3,3-dichlorobenzidine acetoacetanilides, a monoazo pigment identified in the Color Index as CI 12700, CI Solvent Yellow 16, a nitrophenyl amine sulfonamide identified in the Color Index as Foron Yellow SE/GLN, CI Dispersed Yellow 33, 2,5-dimethoxy-4-sulfonanilide phenylazo-4'-chloro-2,5-dimethoxy acetoacetanilide, and Permanent Yellow FGL. The aforementioned pigments are incorporated into the toner composition in various suitable effective amounts providing the objectives of the present invention are

achieved. In one embodiment, these colored pigment particles are present in the toner composition in an amount of from about 2 percent by weight to about 15 percent by weight calculated on the weight of the toner resin particles.

5           For the formulation of developer compositions, there are mixed with the toner particles carrier components, particularly those that are capable of triboelectrically assuming an opposite polarity to that of the toner composition. Accordingly, the carrier particles are selected to be of a negative polarity enabling the toner particles, which are positively  
10 charged, to adhere to and surround the carrier particles. Illustrative examples of carrier particles include iron powder, steel, nickel, iron, ferrites, including copper zinc ferrites, and the like. Additionally, there can be selected as carrier particles nickel berry carriers as illustrated in U.S. Patent 3,847,604, the disclosure of which is totally incorporated herein by  
15 reference. The selected carrier particles can be used with or without a coating, the coating generally containing terpolymers of styrene, methylmethacrylate, and a silane, such as triethoxy silane, reference U.S. Patent 3,526,533, U.S. Patent 4,937,166, and U.S. Patent 4,935,326, the disclosures of which are totally incorporated herein by reference, including  
20 for example KYNAR® and polymethylmethacrylate mixtures (40/60). Coating weights can vary as indicated herein; generally, however, from about 0.3 to about 2, and preferably from about 0.5 to about 1.5 weight percent coating weight is selected.

          Furthermore, the diameter of the carrier particles, preferably  
25 spherical in shape, is generally from about 50 microns to about 1,000 microns, and in embodiments about 175 microns thereby permitting them to possess sufficient density and inertia to avoid adherence to the electrostatic images during the development process. The carrier component can be mixed with the toner composition in various suitable  
30 combinations, however, best results are obtained when about 1 to 5 parts per toner to about 10 parts to about 200 parts by weight of carrier are selected.

          The toner composition of the present invention can be prepared by a number of known methods as indicated herein including  
35 extrusion melt blending the toner resin particles, pigment particles or colorants, and a charge enhancing additive, followed by mechanical attrition. Other methods include those well known in the art such as spray drying, melt dispersion, and extrusion processing. Also, as indicated herein the toner composition without the charge enhancing additive in the bulk

toner can be prepared, followed by the addition of charge additive surface treated colloidal silicas.

5 The toner and developer compositions may be selected for use in electrostatographic imaging apparatuses containing therein conventional photoreceptors providing that they are capable of being charged positively or negatively. Thus, the toner and developer compositions can be used with layered photoreceptors that are capable of being charged negatively, such as those described in U.S. Patent 4,265,990, the disclosure of which is totally incorporated herein by reference.

10 Illustrative examples of inorganic photoreceptors that may be selected for imaging and printing processes include selenium; selenium alloys, such as selenium arsenic, selenium tellurium and the like; halogen doped selenium substances; and halogen doped selenium alloys.

The toner compositions are usually jetted and classified

15 subsequent to preparation to enable toner particles with a preferred average diameter of from about 5 to about 25 microns, and more preferably from about 8 to about 12 microns. Also, the toner compositions preferably possess a triboelectric charge of from about 0.1 to about 2 femtocoulombs per micron as determined by the known charge spectrograph. Admix time for toners are preferably from about 5 seconds to 1 minute, and more specifically from about 5 to about 15 seconds as determined by the known charge spectrograph. These toner compositions with rapid admix characteristics enable, for example, the development of images in electrophotographic imaging apparatuses, which images have

25 substantially no background deposits thereon, even at high toner dispensing rates in some instances, for instance exceeding 20 grams per minute; and further, such toner compositions can be selected for high speed electrophotographic apparatuses, that is those exceeding 70 copies per minute.

30 Also, the toner compositions prepared from resins of the present invention possess desirable narrow charge distributions, optimal charging triboelectric values, preferably of from 10 to about 40, and more preferably from about 10 to about 35 microcoulombs per gram as determined by the known Faraday Cage methods with from about 0.1 to about 5 weight percent in one embodiment of the charge enhancing additive; and rapid admix charging times as determined in the charge spectrograph of less than 15 seconds, and more preferably in some

35 embodiments from about 1 to about 14 seconds.

The following Examples are being supplied to further define various species of the present invention, it being noted that these Examples are intended to illustrate and not limit the scope of the present invention. Parts and percentages are by weight unless otherwise indicated. Comparative Examples are also provided.

#### **COMPARATIVE EXAMPLE I**

**Suspension Free Radical Polymerization of Styrene Without A Stable Free Radical Agent** A suspension of tricalcium phosphate (3.0 g) in a solution of Alkanol (48 mg), a naphthalene sulfonate available from DuPont, in water (100 mL) was added to a modified Parr reactor and the reactor was heated to 80°C over 30 minutes while it was purged with nitrogen. A solution of benzoyl peroxide (2.0 g, 0.008 mol) in styrene (78 g, 0.75 mol) was added to the reactor under 60 pounds per square inch of nitrogen and the reaction was continued at 80°C for three hours and twenty minutes. The reaction was then heated to 95°C and continued at that temperature for an additional two hours and twenty minutes. Samples were removed from the reactor at the time interval or reaction time in minutes indicated in Table I, cooled, treated with concentrated nitric acid to dissolve the suspending agent, rinsed with water and dried. The molecular weight properties of the intermediate materials and the final polystyrene product are shown in Table I. Polydispersity ( $M_w/M_n$ ) is indicated in the column labeled PD.

#### **EXAMPLE I**

**Suspension Free Radical Polymerization of Styrene with a Stable Free Radical Agent Additive (TEMPO)** A suspension of tricalcium phosphate (3.0 g) in a solution of Alkanol (48 mg) in water (100 mL) was added to a modified Parr reactor and the reactor was heated to 80°C over 30 minutes while it was purged with nitrogen. A solution of benzoyl peroxide (3.2 g, 0.013 mol) and TEMPO (1 g, 0.0064 mol), a stable free radical, in styrene (78 g, 0.75 mol) was added to the reactor under 60 pounds per square inch of nitrogen and the reaction was continued at 80°C for three hours and thirty minutes. The reaction was then heated to 95°C and continued at that temperature for an additional one hour and twenty minutes. Samples were removed from the reactor at time intervals as indicated in Table II, cooled, treated with concentrated nitric acid to dissolve the suspending agent, rinsed with water and dried. The molecular weight properties of the intermediate materials and the final polystyrene product are shown in Table II.

Table I

Comparative Example I Samples	Wt. SFR (grams)	Reaction Time(min.)	$M_n(10^3)$	$M_w(10^3)$	PD
Ia	0	60	18.9	33.0	1.75
Ib	0	120	17.9	32.8	1.83
Ic	0	200	16.4	32.0	1.95
Id	0	280	13.0	30.6	2.36

Table I shows the change of molecular weight with time of a typical suspension free radical polymerization reaction (control reaction). Note that high molecular weight polymers are obtained immediately (Ia) since the polymer chains are initiated and grow in milliseconds to a given length and then terminate. As the reaction continues and monomer is consumed, the  $M_n$  and  $M_w$  are reduced because the polymer chains initiated later in the reaction have less free monomer available for continued growth and so terminate at shorter chain lengths. As the reaction proceeds and the viscosity of the reaction medium increases, the polydispersity (PD), that is the molecular weight distribution ( $M_w/M_n$ ), of the resin increases from 1.75 to 2.36.

Table II

Example I Samples	Wt. SFR (grams)	Reaction Time(min.)	$M_n(10^3)$	$M_w(10^3)$	PD
Ia	1.0	60	1.6	4.3	2.76
Ib	1.0	95	9.4	18.1	1.93
Ic	1.0	200	17.8	32.9	1.85
Id	1.0	310	20.4	38.3	1.87

Table II shows the molecular weight changes of a free radical polymerization in the presence of a stable free radical agent. At the beginning of the reaction (Ia) the molecular weight is very low but continues to increase as the reaction proceeds indicating that pseudoliving chains continue to add monomer units. In comparative Example I, in some cases monomer only adds to a given polymer chain for a fraction of a second and then termination occurs. In the presence of a stable free radical agent, monomers continue to add to a given chain over the course



of several hours and will continue to add monomer units for as long as there is monomer present in the reaction mixture. The polydispersity of the final product is smaller or less disperse in the stable free radical moderated polymerization of Example I (Id) than in the Control Example I (Id). When Example I reaction is performed at temperatures below 100 degrees centigrade and the TEMPO to BPO molar ratio is less than one as is the case in Example I, only modest improvement, from 2.36 to 1.87, in polydispersity is achieved.

#### **EXAMPLE II**

##### **Bulk Polymerization of Styrene with a Stable Free Radical Agent (TEMPO)**

A solution of styrene (15 g, 0.144 mol), benzoyl peroxide (0.385 g, 0.0016 mol) and TEMPO (0.292 g, 0.0019 mol) was heated under argon for 3.5 hours at 95°C. It is assumed, based on the half-life of benzoyl peroxide (BPO) and that TEMPO is known to act as a promoter for the dissociation of benzoyl peroxide, that no benzoyl peroxide remains in the reaction mixture after this time. The reaction mixture is heated to 123°C over a period of 45 minutes and the reaction was continued at this temperature for 69 hours. Samples were removed from the reaction mixture over the course of the reaction as indicated and the molecular weight properties of the polystyrene products and percent conversion values of these samples are summarized in Table III.

Example II demonstrates that the reaction can be conveniently accomplished in the absence of a solvent or in bulk. As indicated by the incremental increase in molecular weight the reaction appears to be proceeding via a pseudoliving mechanism. The molar ratio of TEMPO to BPO was 1.3 compared to Experiment I which had a ratio of 0.5. After the 95°C heating period no polymeric material was observed by gel permeation chromatography(GPC). Reacting this mixture at 123°C resulted in very narrow polydispersities (1.26). In Example II, polydispersities below the aforementioned theoretical calculated value of 1.5 for the free radical polymerization of styrene, were achieved. Note also that the polydispersity of the polystyrene product does not increase with percent conversion. This Example also provides a demonstration of achieving high percent conversions of monomer to polymer while retaining narrow polydispersities in the polymeric resin products.

#### **EXAMPLE III**

**Solution Polymerization of Styrene in Toluene with a Stable Free Radical Agent Additive** A solution of styrene (7.5 g, 0.072 mol), benzoyl peroxide (0.150g, 0.0006 mol) and TEMPO (0.097 g, 0.0006 mol) was added, under

argon, to refluxing toluene (10 mL) heated in an oil bath maintained for 7 hours at 125°C. The solution was cooled and maintained at room temperature for 16 hours. The solution was thereafter heated for an additional 5.75 hours. Samples were withdrawn from the reaction mixture as indicated and the molecular weight properties of these polystyrene intermediates and products are shown in Table IV. The Example demonstrates that stable free radical agent moderated reactions can be performed in solution. The molecular weights increase with time in an incremental or linear fashion and narrow polydispersities are obtained.

Table III

Example II	Reaction Time (hr)	M <sub>n</sub> (10 <sup>3</sup> )	M <sub>w</sub> (10 <sup>3</sup> )	PD	Conversion (%)
IIa	21	1.7	2.2	1.28	20
IIb	29	3.2	4.1	1.27	51
IIc	45	6.8	8.2	1.21	76
IIId	69	8.7	10.9	1.26	90

Other control reactions were conducted where the reaction temperature was lower (95°C) and the TEMPO to BPO molar ratio was lower, for example, 0.5 compared to 1.0 of Example III. The reactions employing lower temperatures and lower TEMPO to BPO molar ratios failed to proceed by a pseudoliving mechanism and appeared to proceed by a conventional free radical polymerization mechanism and as a result, high molecular weight polystyrene material was obtained early in the reaction and the polydispersity was not significantly narrower than a control. That is, at lower reaction temperatures and lower TEMPO to BPO molar ratios the polydispersity of the product polystyrenes were higher than with the conditions used for the stable free radical moderated polymerizations of styrene.

#### EXAMPLE IV

**Bulk Polymerization of Styrene at 150°C.** A solution of styrene (15 g, 0.144 mol), benzoyl peroxide (0.150 g, 0.00062 mol) and TEMPO (0.125 g, 0.00080 mol) was heated, under argon, in an oil bath maintained at 150°C for 6.5 hours. The molecular weight properties of the resulting polystyrene polymer are shown in Table V. By increasing the oil bath temperature from 125°C to 150°C, the reaction times can be dramatically

reduced. In Example II, the oil bath temperature was 123°C and the reaction time for 90% conversion required about 69 hours. With an oil bath temperature of 150°C, 86% conversion can be obtained in 6.5 hours. In contrast to Example II no prior reaction at 95°C was required and no broadening of the polydispersity results even when all reactants and reagent are immediately reacted together at high temperature.

Table IV

Sample	Reaction Time (hr)	M <sub>n</sub>	M <sub>w</sub>	PD
IIIa	1.25	680	1725	2.5
IIIb	3.6	1132	2119	1.9
IIIc	7.1	1997	2743	1.4
IIId	12.9	3411	4409	1.3

Table V

Example V	M <sub>n</sub> (10 <sup>3</sup> )	M <sub>w</sub> (10 <sup>3</sup> )	PD	Conversion (%)
IVa	14.0	17.3	1.24	86

#### EXAMPLE V

**Bulk Polymerization of Styrene at 150°C.** A solution of styrene (15 g, 0.144 mol), benzoyl peroxide (0.075 g, 0.00031 mol) and TEMPO (0.063 g, 0.00040 mL) was heated, under argon, in an oil bath maintained at 150°C for 7 hours. The molecular weight properties of the resulting polystyrene polymer are shown in Table VI.

#### EXAMPLE VI

**Bulk Polymerization of Styrene at 150°C.** A solution of styrene (15 g, 0.144 mol), benzoyl peroxide (0.075 g, 0.00031 mol) and TEMPO (0.073 g, 0.00047 mol) was heated, under argon, in an oil bath maintained at 150°C for 7 hours. The molecular weight of the resulting polystyrene polymer are shown in Table VI.

#### EXAMPLE VII

**Bulk Polymerization of Styrene at 150°C.** A solution of styrene (15g, 0.144 mol), benzoyl peroxide (0.075g, 0.00031 mol) and TEMPO (0.087g, 0.00056

mol) was heated, under argon, in an oil bath maintained at a temperature of 150°C for 7 hours. The physical properties of the resulting polystyrene polymer are shown in Table VI.

Table VI

Example	TEMPO/ BPO	Mn(10 <sup>3</sup> )	Mw(10 <sup>3</sup> )	PD	Conversion (%)
V	1.3	26.9	35.4	1.3	86
VI	1.5	16.0	21.1	1.2	92
VII	1.8	13.9	17.1	1.3	86

In Examples V, VI and VII, the ratio of benzoyl peroxide to styrene is kept constant while the molar ratio of TEMPO to benzoyl peroxide is varied. It can be seen that the TEMPO/BPO molar ratio has little affect on the conversion when the reaction is performed in an oil bath maintained at 150°C. It is believed that the difference in conversions of 86% and 92% is within experimental error of the method used to calculate percent conversion as determined by gas chromatography on a Carbowax 20M column, available from Supelco.

There is a pronounced influence of the TEMPO/BPO molar ratio on the molecular weight of the resulting polymer. As the TEMPO/BPO molar ratio is increased, the molecular weight of the resulting polymer decreases indicating that the more TEMPO that is present, the more efficient the free radical initiator, that is the same amount of free radical initiator is capable of initiating more polymer chains sooner than at lower TEMPO to BPO molar ratios. Therefore, it would appear that the free radical initiator efficiency can be influenced by the amount of stable free radical agent used.

#### EXAMPLE VIII

**Bulk Polymerization of Styrene for High Molecular Weight Polystyrene** A solution of styrene (15 g, 0.144 mol), benzoyl peroxide (0.025 g, 0.00010 mol) and TEMPO (0.021 g, 0.00013 mol) was heated, under argon, in an oil bath maintained at 150°C for 2.5 hours. The molecular weight properties of the resulting polymer are shown in Table VII. This experiment demonstrates that the molecular weight of the product polymer resin can be controlled by varying the amount of BPO used and that high molecular weight resins can be obtained while maintaining narrow polydispersities.

Table VII

Example	M <sub>n</sub> (10 <sup>3</sup> )	M <sub>w</sub> (10 <sup>3</sup> )	PD
VIII	57.7	67.0	1.16

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**EXAMPLE IX**

**Suspension Copolymerization of Styrene and Myrcene Without a Stable Free Radical Agent** A suspension of to dissolve residual suspension agent tricalcium phosphate (3.0 g) in a solution of Alkanol (48 mg) in water (100 mL) was added to a modified Parr reactor and the reactor was heated to 95°C over 30 minutes while it was purged with nitrogen. A solution of benzoyl peroxide (5.0g, 0.021 mol) and TAEC[O,O-t-amyl-O-(2-ethylhexyl)monoperoxycarbonate] (0.2 mL), in styrene (46.8 g, 0.45 mol) and myrcene (10.6 g, 0.08 mol) was added to the reactor under 60 pounds per square inch of nitrogen and the reactor was heated at 95 °C for 192 minutes, heated to 125 °C over 40 minutes and maintained at 125°C for one hour. The reactor was cooled and the copolymer was removed from the reactor, treated with concentrated nitric acid, rinsed with water to yield a thick oil that gave a slightly off-white solid when precipitated from a methylene chloride solution into methanol. The molecular weight properties of the styrene-myrcene copolymer material are shown in Table VIII.

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**EXAMPLE X**

**Suspension Copolymerization of Styrene and Myrcene with a Stable Free Radical Agent ( TEMPO)** A suspension of tricalcium phosphate (3.0 g) in a solution of Alkanol (48 mg) in water (100 mL) was added to a modified Parr reactor and the reactor was heated to 95°C over 30 minutes while it was purged with nitrogen. A solution of benzoyl peroxide (0.30 g, 0.012 mol) and TEMPO (0.20 g, 0.0013 mol), in styrene (60 g, 0.58 mol) and myrcene (10 g, 0.07 mol) was added to the reactor under a pressure of nitrogen and the reactor was heated to 143°C over 15 minutes and then maintained at that temperature for 7.5 hours. The reactor was cooled and the copolymer was removed from the reactor, treated with concentrated nitric acid, rinsed with water to yield a thick oil that gave a slightly off-white solid when precipitated from a methylene chloride solution into methanol. The molecular weight properties of the styrene-myrcene copolymer material are shown in Table VIII. The <sup>1</sup>H NMR of the sample confirmed the product to be a copolymer of styrene and myrcene.

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Table VIII

Example	M <sub>n</sub> (10 <sup>3</sup> )	M <sub>w</sub> (10 <sup>3</sup> )	PD
IX	8.7	38.9	4.4
X	19.2	31.3	1.6

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Examples IX and X demonstrate that copolymers can be obtained and that narrow polydispersities are maintained using processes of the instant invention. The control reaction Example IX is a typical free radical suspension polymerization process that gives a copolymer with approximately the same M<sub>w</sub> as the copolymer prepared in the presence of TEMPO as Example X. The Example X reaction performed in the presence of TEMPO yielded a copolymer with a polydispersity of 1.6 which was considerably lower than the polydispersity 4.4 value obtained without a stable free radical agent present.

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In Example X, in the presence of TEMPO the monomer to BPO molar ratio was 1:542, whereas, in the control reaction in Example IX the ratio was 1:25. It would appear that the TEMPO has an affect on the initiator efficiency and greatly improves it. This enhanced efficiency feature allows the use of considerably less initiator to prepare a copolymer of a given molecular weight as compared to a free radical polymerization process without a stable free radical agent present.

#### EXAMPLE XI

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**Magnetic Toner Preparation and Evaluation** The polymer resin (74 weight percent of the total mixture) obtained by the stable free radical polymerization processes in Example I may be melt extruded with 10 weight percent of REGAL 330® carbon black and 16 weight percent of MAPICO BLACK® magnetite at 120°C, and the extrudate pulverized in a Waring blender and jetted to 8 micron number average sized particles. A positively charging magnetic toner may be prepared by surface treating the jetted toner (2 grams) with 0.12 gram of a 1:1 weight ratio of AEROSIL R972® (Degussa) and TP-302 a naphthalene sulfonate and quaternary ammonium salt (Nachem/Hodogaya SI) charge control agent.

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Developer compositions may then be prepared by admixing 3.34 parts by weight of the aforementioned toner composition with 96.66 parts by weight of a carrier comprised of a steel core with a polymer mixture thereover containing 70 percent by weight of KYNAR®, a polyvinylidene fluoride, and 30 percent by weight of polymethyl

methacrylate; the coating weight being about 0.9 percent. Cascade development may be used to develop a Xerox Model D photoreceptor using a "negative" target. The light exposure may be set between 5 and 10 seconds and a negative bias used to dark transfer the positive toned images from the photoreceptor to paper.

Fusing evaluations may be carried out with a Xerox 5028® soft silicone roll fuser, operated at 7.62 cm (3 inches) per second.

The minimum fix and hot offset temperatures of stable free radical polymerization polymers having narrow polydispersities as toners are expected to be improved over toners prepared from resins synthesized by a free radical polymerization process without a stable free radical agent present affording broad polydispersities. The actual fuser roll temperatures may be determined using an Omega pyrometer and was checked with wax paper indicators. The degree to which a developed toner image adhered to paper after fusing is evaluated using a Scotch® tape test. The fix level is expected to be excellent and comparable to that fix obtained with toner compositions prepared from other methods for preparing toners having resins with high molecular weights and narrow polydispersities. Typically greater than 95 percent of the toner image remains fixed to the copy sheet after removing a tape strip as determined by a densitometer.

Images may be developed in a xerographic imaging test fixture with a negatively charged layered imaging member comprised of a supporting substrate of aluminum, a photogenerating layer of trigonal selenium, and a charge transport layer of the aryl amine N,N'-diphenyl-N,N'-bis(3-methylphenyl)1,1'-biphenyl-4,4'-diamine, 45 weight percent, dispersed in 55 weight percent of the polycarbonate MAKROLON®, reference U.S. Patent 4,265,990, the disclosure of which is totally incorporated herein by reference; images for toner compositions prepared from the copolymers derived from for example, Example XI are expected to be of excellent quality with no background deposits and of high resolution over an extended number of imaging cycles exceeding, it is believed, about 75,000 imaging cycles.

Other toner compositions may be readily prepared by conventional means from the polymer and copolymer resins of the present invention including colored toners, single component toners, multi-component toners, toners containing special performance additives, and the like.

The aforementioned stable free radical agent moderated polymerization process may be applied to a wide range of organic monomers to provide novel toner resin materials with desirable electrophotographic properties. For example, the block copolymers have application as dispersants for photoreceptor pigments. The multimodal resins have application to low melt resins and certain monomodal resins may be used to modify the surface of carbon black and pigment particles to make the pigment particles more miscible with a host polymer or dispersing medium. Narrow molecular weight resins such as poly(styrene-butadiene) find application as improved toner resins for general application.

Other modifications of the present invention may occur to those skilled in the art based upon a review of the present application and these modifications, including equivalents thereof, are intended to be included within the scope of the present invention.



WHAT IS CLAIMED IS:

1. A free radical polymerization process for the preparation of a thermoplastic resin or resins comprising:

5 heating from about 100 to about 160°C a mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form said thermoplastic resin or resins with a high monomer to polymer conversion and a narrow polydispersity;

10 cooling said mixture;  
optionally isolating said thermoplastic resin or resins; and  
optionally washing and drying said thermoplastic resin or resins.

2. A free radical polymerization process for the preparation of thermoplastic resins comprising:

15 heating a first mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form a first intermediate product resin;

optionally cooling said first mixture;  
adding to said first intermediate product resin a second  
20 mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound, wherein said polymerizable monomer compound of said second mixture contains the same components as said polymerizable monomer compound of said first mixture, and said free radical initiator and said stable free radical agent of  
25 said second mixture are the same or different from said free radical initiator and said stable free radical agent of said first mixture, and wherein there is formed a combined mixture;

heating said combined mixture to form a third mixture comprised of a mixture of thermoplastic resins comprised of a first product resin formed from said first intermediate product resin and added said  
30 second monomer and a second product resin formed from said second monomer;

cooling said third mixture;  
optionally isolating said mixture of thermoplastic  
35 product resins from said third mixture; and

optionally washing and drying said mixture of thermoplastic resins and wherein said first product resin and said second product resin each possess a narrow polydispersity.

3. A free radical polymerization process for the preparation of a block copolymer thermoplastic resin or resins comprising:

heating a first mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form a first intermediate product resin;

optionally cooling said first mixture;

optionally isolating said first intermediate product resin;

adding to said first intermediate product resin a second mixture comprised of at least one polymerizable monomer compound, wherein said polymerizable monomer compound of said second mixture is different from said polymerizable monomer compound of said first mixture, to form a combined mixture;

heating said combined mixture to form a third mixture comprised of a block copolymer thermoplastic resin comprised of a first product resin formed from said first intermediate product resin and added said second monomer;

cooling said third mixture;

optionally isolating said block copolymer thermoplastic resin from said third mixture; and

optionally washing and drying said block copolymer thermoplastic resin.

4. A process in accordance with claim 1 wherein the heating is conducted in a solvent or diluent.

5. A process in accordance with claim 1 wherein the heating of said mixture is conducted with said mixture as a suspension in water or in a polar liquid which is not miscible with said monomer compound.

6. A process in accordance with claim 1 wherein the heating of said mixture is conducted with said mixture neat or in the absence of solvent.

7. A process in accordance with claim 1 wherein the thermoplastic resin product has a polydispersity of from about 1.1 to about 1.45 and a monomer to polymer conversion of greater than 50 percent.

8. A process in accordance with claim 1 wherein the heating is from about 1 to 60 hours.

9. A process in accordance with claim 1 wherein said polydispersity of said thermoplastic resin remains about constant throughout said polymerization process.

10. A process in accordance with claim 1 wherein said free radical initiator is selected from the group consisting of organic peroxides, azobisalkylnitriles, peroxy carbonates, and mixtures thereof.

5 11. A process in accordance with claim 1 wherein the stable free radical agent is comprised of a nitroxide stable free radical.

12. A process in accordance with claim 1 wherein the stable free radical agent is comprised of nitroxide stable free radicals selected from the group of consisting of 2,2,5,5-tetramethyl-1-pyrrolidinyloxy, derivatives thereof, 2,2,6,6-tetramethyl-1-piperidinyloxy, derivatives thereof, and mixtures thereof.

10 13. A process in accordance with claim 1 wherein the stable free radical agent to free radical initiator molar ratio is from about 0.4 to 2.5.

14. A process in accordance with claim 1 wherein the stable free radical agent to free radical initiator molar ratio is from about 0.9 to 1.8.

15 15. A process in accordance with claim 1 wherein the monomer to free radical initiator molar ratio is from about 100:1 to about 10,000:1.

20 16. A process in accordance with claim 1 wherein said monomer to polymer conversion is at least 90 percent by weight.

17. A process in accordance with claim 1 wherein the monomer compound is selected from the group consisting of styrene and derivatives thereof, conjugated dienes and derivatives thereof, acrylates and derivatives thereof, and mixtures thereof.

25 18. A process in accordance with claim 1 wherein said heating is from about 110°C to about 160°C.

19. A process in accordance with claim 1 wherein said thermoplastic resin has a gel content of from 0.0 to about 0.5 weight percent.

30 20. A process in accordance with claim 1 wherein the weight average molecular weight ( $M_w$ ) of the resin or resins are from 10,000 to 200,000.

21. A process in accordance with claim 1 wherein the heating is from about 100 to about 160 °C and wherein the polymeric chains of said resin are formed simultaneously at from about 0 to 10 minutes after said heating has attained about 100 °C.

22. A process in accordance with claim 1 further comprising adding an organic sulfonic or organic carboxylic acid during heating of

said mixture thereby increasing the rate of formation of said thermoplastic resin or resins from said polymerization of said monomer compound.

23. A process in accordance with claim 1 further comprising adding a tertiary amine promoter compound to said mixture thereby increasing the rate of dissociation of said free radical initiator and where said free radical initiator is an organic peroxide.

24. A process in accordance with claim 1 wherein said thermoplastic resin or resins has a polydispersity of from about 1.1 to about 2.0 and a monomer to polymer conversion of about 50 to about 90 percent.

25. A process in accordance with claim 1 wherein the molar ratio of monomer to stable free radical agent to free radical initiator is from about 100:0.2:1 to about 10,000:2.5:1.

26. A free radical polymerization process for the preparation of a thermoplastic resin or resins comprising:

heating from about 100 to about 160°C for an effective time period a water suspension mixture comprised of a peroxide free radical initiator, a nitroxide stable free radical agent, and at least one polymerizable monomer compound to form said thermoplastic resin or resins;

cooling said mixture;  
optionally isolating said thermoplastic resin or resins; and  
optionally washing and drying said thermoplastic resin or resins, wherein said thermoplastic resin possesses a narrow polydispersity of from about 1.1 to about 1.5, a modality of 1, and wherein the process affords a monomer to polymer conversion of from about 10 to about 100 percent.

27. A polymer or copolymer resin composition obtained by the process of claim 1 wherein said resin or resins have a weight average molecular weight ( $M_w$ ) of from about 10,000 to 200,000 and a number average molecular weight ( $M_n$ ) of from about 9,000 to about 100,000 and a polydispersity of about 1.1 to 2.0.

28. A toner composition comprised of pigment particles, and resin comprised of at least one resin obtained from the polymerization process of claim 1.

29. A free radical polymerization process for the preparation of a multiblock copolymer thermoplastic resin or resins comprising:

heating a first mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form a first intermediate product resin;

optionally cooling said first mixture;

5 optionally isolating said first intermediate product resin;

adding to said first intermediate product resin a second mixture comprised of at least one polymerizable monomer compound, wherein said polymerizable monomer compound of said second mixture is different from said polymerizable monomer compound of said first mixture, to form a combined mixture;

10 heating said combined mixture to form a third mixture comprised of a block copolymer thermoplastic resin comprised of a first product resin formed from said first intermediate product resin and added said second monomer;

15 cooling said third mixture;

optionally isolating said third mixture;

sequentially repeating the preceding steps of adding, heating and cooling, N times, to form a fourth mixture containing a multiblock copolymer thermoplastic resin or resins having N+2 blocks and wherein N is the number of times said sequence is repeated;

20 optionally isolating said multiblock copolymer thermoplastic resin from said fourth mixture; and

optionally washing and drying said multiblock copolymer thermoplastic resin and wherein said multiblock copolymer thermoplastic resin possesses a narrow polydispersity and a modality of 1.

30. A process in accordance with claim 29, wherein N is from 1 to about 20.

31. A process in accordance with claim 2, wherein the mixture of thermoplastic resins possesses a modality of 2.

30 32. A process in accordance with claim 3, wherein said block copolymer possesses a narrow polydispersity and a modality of 1.

33. A toner composition comprised of pigment particles, and resin comprised of resins obtained from the polymerization process of claim 2.

35 34. A toner composition comprised of pigment particles, and resin comprised of at least one resin obtained from the polymerization process of claim 3.

35. A polymer or copolymer resin composition obtained by the process of claim 2 wherein said resins have a weight average molecular

weight ( $M_w$ ) of from about 10,000 to 200,000 and a number average molecular weight ( $M_n$ ) of from about 9,000 to about 100,000 and a polydispersity of about 1.1 to 2.0.

5        36.    A polymer or copolymer resin composition obtained by the process of claim 3 wherein said block copolymer resin have a weight average molecular weight ( $M_w$ ) of from about 10,000 to 200,000 and a number average molecular weight ( $M_n$ ) of from about 9,000 to about 100,000 and a polydispersity of about 1.1 to 2.0.

10       37.    A process in accordance with claim 1 wherein said heating is for a period of from about 30 minutes to 30 hours.

38.    A process in accordance with claim 1 wherein the stable free radical agent to free radical initiator molar ratio SFR:INIT is from about 1.2 to 1.8.

15       39.    A process in accordance with claim 26 wherein said effective time period is from about 30 minutes to 10 hours.

40.    A process in accordance with claim 1 wherein said high monomer to polymer conversion is of from about 10 to about 100 percent and said narrow polydispersity is in excess of about 1.0 to about 2.0.

20       41.    A process in accordance with claim 1 wherein said free radical initiator has a half life of less than or equal to 10 minutes at above 100°C.

42.    A process in accordance with claim 1 wherein said free radical initiator has a half life of less than or equal to 1 minute at above 100°C.

25       43.    A process in accordance with claim 1 wherein said free radical initiator has a half life of from about 5 seconds to about 10 minutes at above 100°C.

44.    A process in accordance with claim 1 wherein said high conversion is from about 50 to 100 percent.

30       45.    A process in accordance with claim 1 wherein said narrow polydispersity is from about 1.1 to about 1.45.

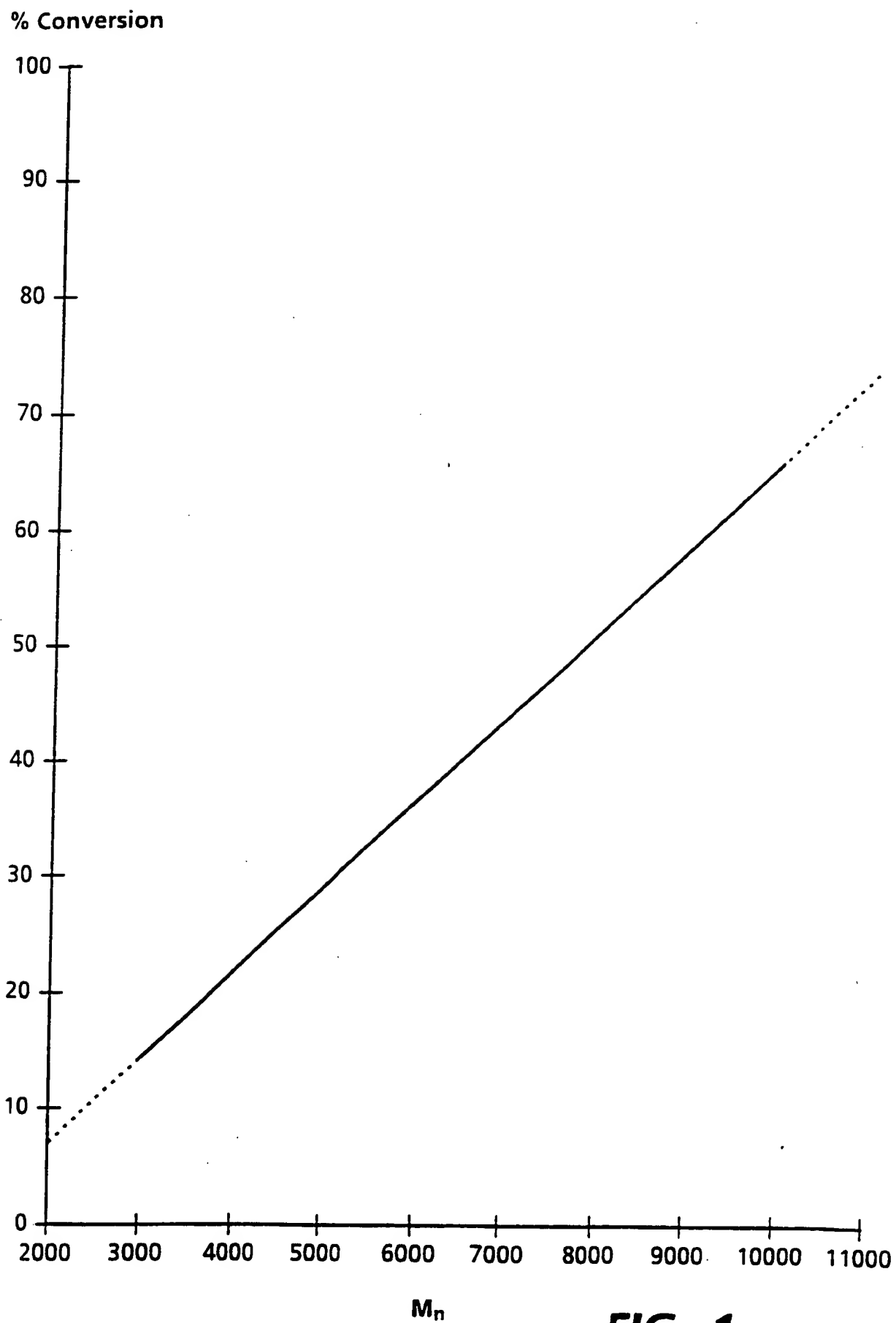
46.    A process in accordance with claim 1 wherein said narrow polydispersity is from about 1.1 to about 1.45 and wherein said conversion is from about 10 to 100 percent.

35       47.    A free radical polymerization process for the preparation of a thermoplastic resin or resins comprising heating from about 100 to about 160°C a mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form said thermoplastic resin or resins with a narrow polydispersity.

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- 5        48.    A polymerization process for the preparation of a thermoplastic resin or resins comprising heating from about 100 to about 160°C a mixture comprised of a free radical initiator, a stable free radical agent, and at least one polymerizable monomer compound to form said thermoplastic resin or resins with a high monomer to polymer conversion and a narrow polydispersity.

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**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(5) : C08F 299/00

US CL : 525/267

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 430/109; 525/267, 273, 299, 316; 526/204, 220, 328, 340, 340.1, 346, 347

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CAS, APS: stable radical, polymeric?

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	J. AM. CHEM. SOC., 1983, (WEBSTER et al.), Group Transfer Polymerization I, 5706-5708.	27, 35, 36
X	MACROMOL., 1987, (SOGAH et al.) Group Transfer Polymerization. 1473-1488, especially Table I, 1478.	27, 35, 36
A	US, A, 4,581,429 (SOLOMON et al.) 08 APRIL 1986.	1-27, 29-32, 35-36
X	MACROMOL., 1991, (KENNEDY et al.) "Polyisobutylene-Containing Block Copolymers by Sequential Monomer Addition. 5....", 6572-6577, especially Tables II and III at 6574, 6575, respectively.	27, 35, 36

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be part of particular relevance "E" earlier document published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed		"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
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Date of the actual completion of the international search 29 DECEMBER 1993	Date of mailing of the international search report MAR 07 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. NOT APPLICABLE	Authorized officer <i>Joseph L. Schofer</i> JOSEPH L. SCHOFER Telephone No. (703) 308-2351

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,628,019 (SUEMATSU et al.) 10 AUGUST 1986. See col. 3, lines 34 to 66.	28, 33, 34
Y	US, A, 3,974,078 (CRYSTAL) 10 AUGUST 1976. See col. 4 line 54 to column 5, line 33.	28, 33, 34
Y	US, A, 3,965,021 (CLEMENS et al.) 22 JUNE 1976. See col. 3, line 14 to column 6, line 19.	28, 33, 34

**Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)**

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
  
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

**Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)**

This International Searching Authority found multiple inventions in this international application, as follows:  
(Form PCT/ISA/206 Previously Mailed.)

Group I, claims 1-27, 29-32 and 35-48, drawn to processes of polymerization and products thereof, classified in Class 525 subclass 267;

Group II, claims 28, 33 and 34, drawn to toner compositions, classified in class 430, subclass 109;

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
  
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
  
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
  
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐  
  
☐

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.